Triggering on Long-Lived Particles decaying to Hadronic Showers in CMS Muon System

Martin Kwok, Cristian Pena, Sergo Jindariani(FNAL)
Sven Dildick ,Paul Padley (Rice University)
Nik Menendez, Darin Acosta(U of Florida)
Christina Wang, Si Xie, Nathan Suri (Caltech)

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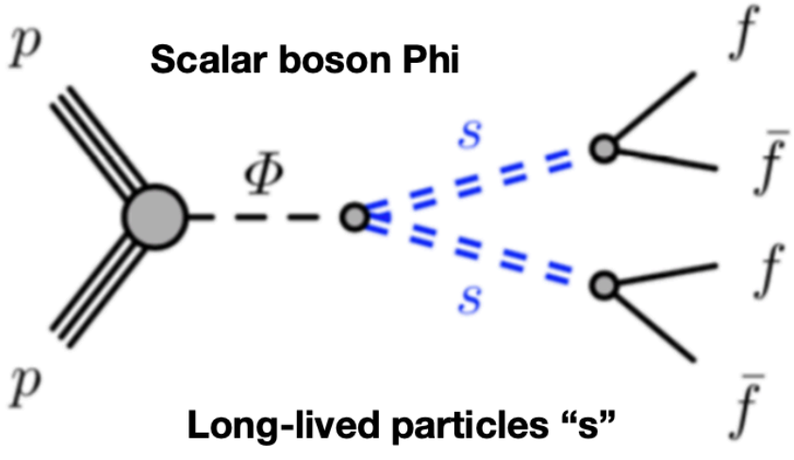
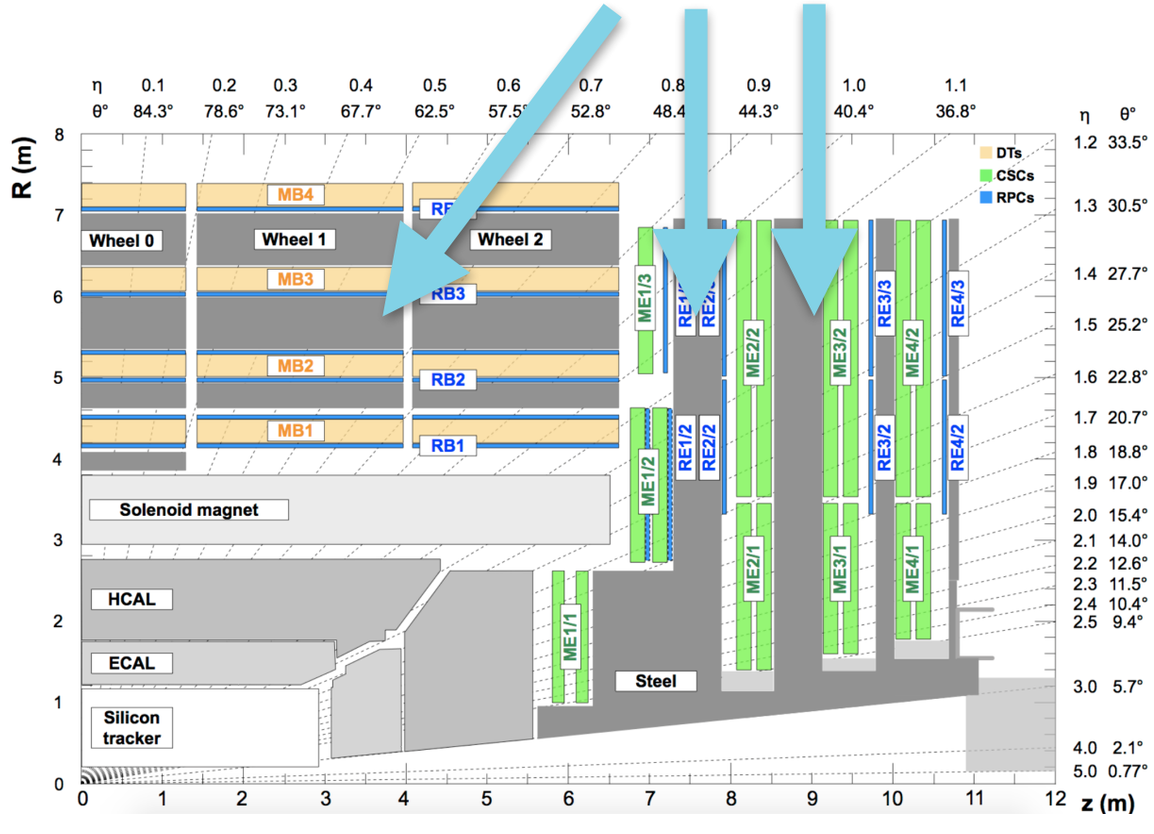
Motivation

- Long-lived particles often arise in BSM physics
  - Small couplings, suppressed decay phase space due to small mass splittings
  - Less well-covered in traditional searches
  - Esp. LLP with longer lifetime (>1m)
- Steel between muon stations can act as absorbers in a sampling calorimeter
  - LLP decaying in the muon system could leave a distinctive high multiplicity signature
  - Naturally cover LLP with longer lifetime
  - No shielding between muons stations in ATLAS in forward region



Shielding of 12-27 interaction length



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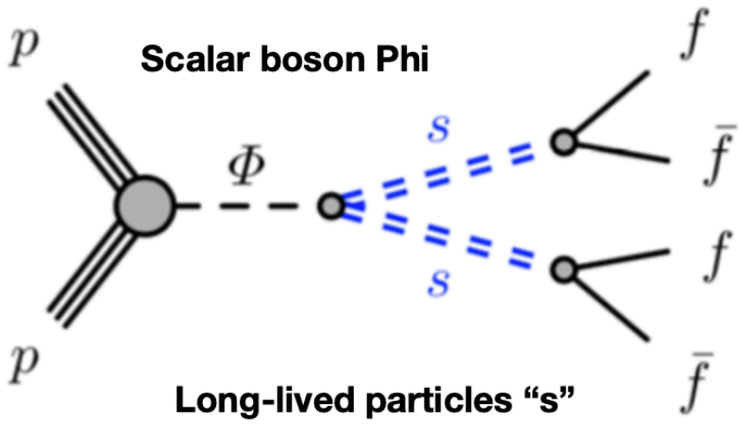
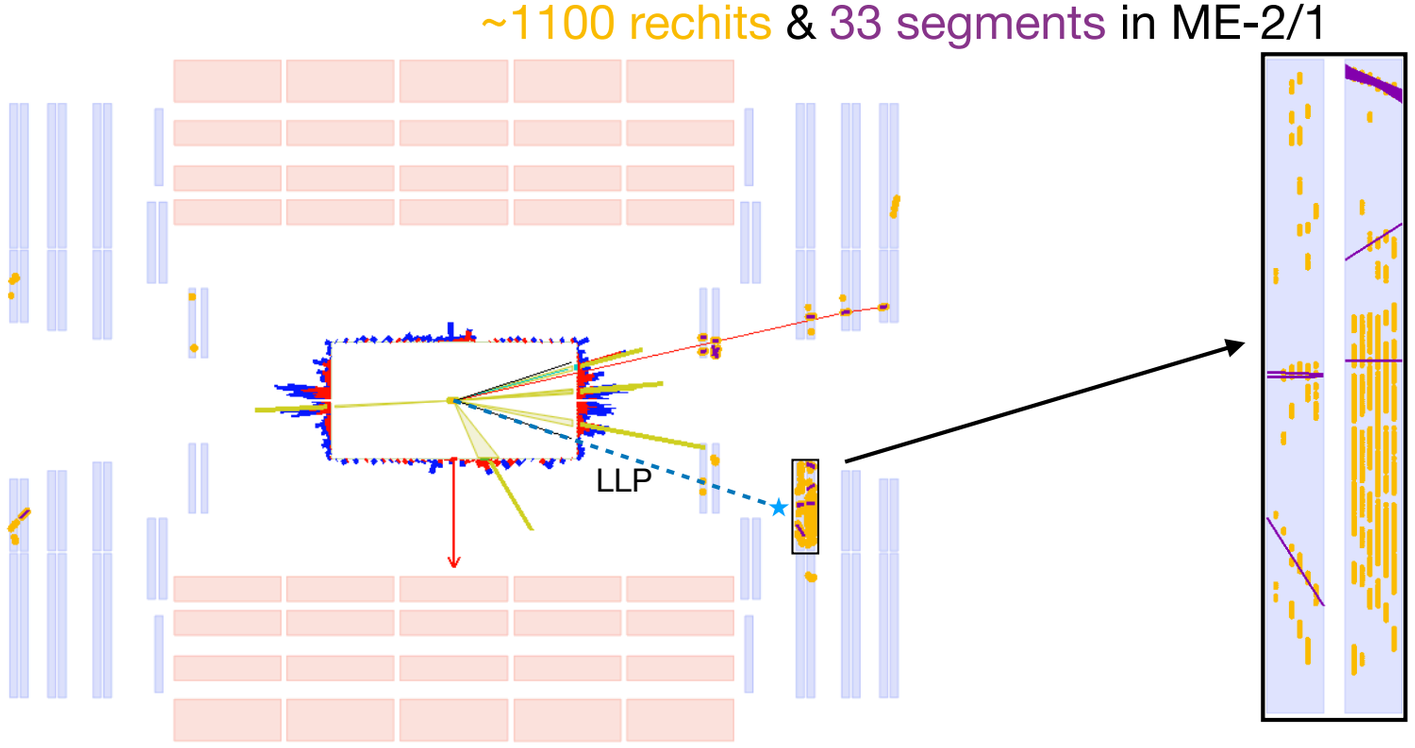
LLP shower in CMS Muon system

- Example signal: Higgs coupled to neutral LLPs decaying into quarks
- No dedicated triggers in CMS for this unique signature in muon system
  - Analysis looking for showers in muon system could take a hit in signal acceptance (e.g. using high MET triggers only gives <1% acceptance)
- This talk: effort to develop new trigger paths to target this signature
  - Focus on the CSC system in the endcap region
  - L1 implementation, HLT estimation

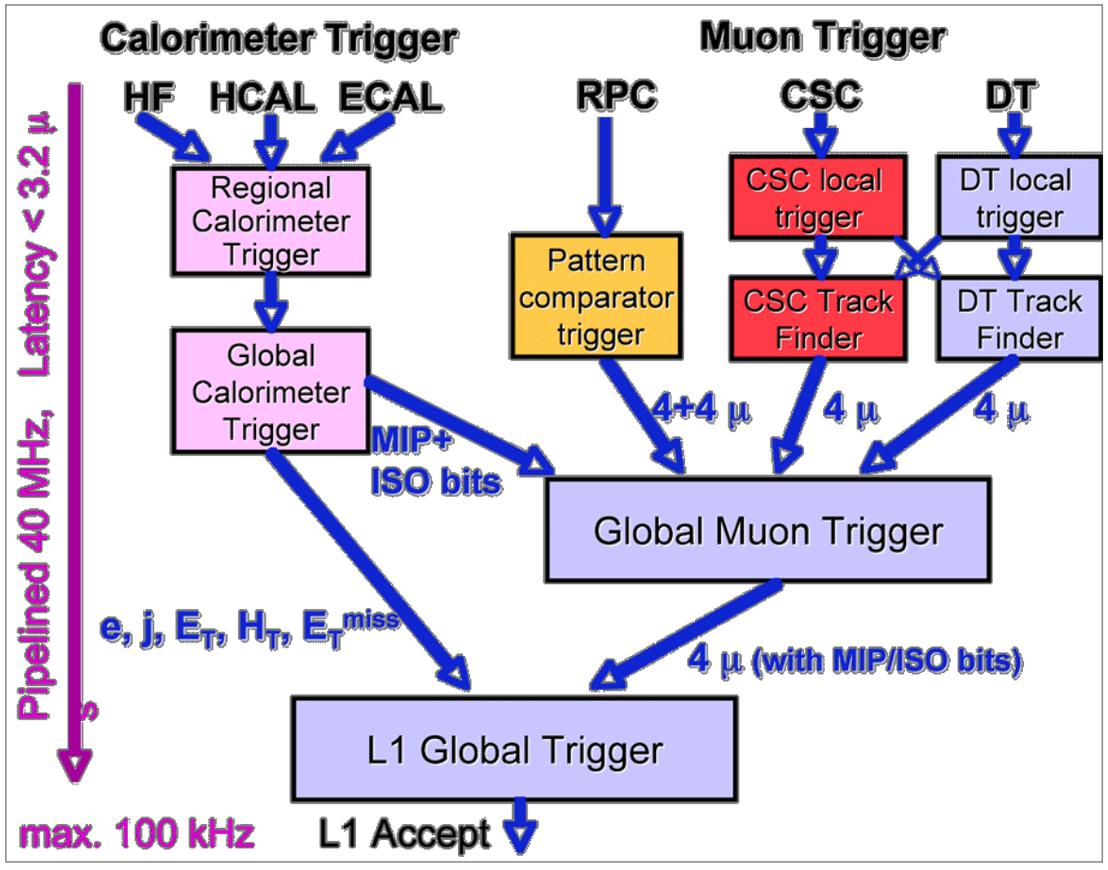




Overview of CMS trigger system

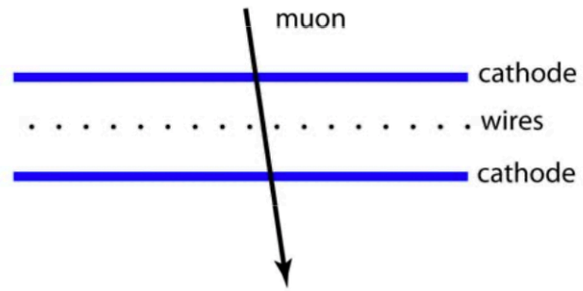
- Two tiers of triggering:
  - Level 1:
    Custom electronics (ASIC/FPGA) operating at 40MHz, total bandwidth 100 kHz
  - HLT:
    Software based triggers after L1, total bandwidth ~1 kHz

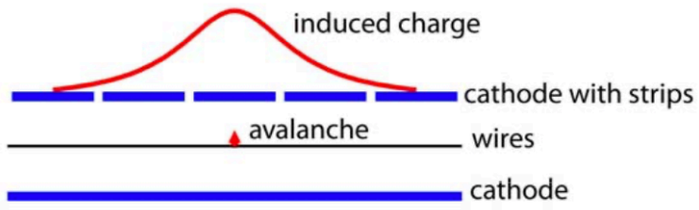
- CSC is the main sub-detector for muon trigger in the forward region
  - Each chamber operates as multiword proportional chambers (MWPC)
  - Each chamber reconstructs local track segments and sends to Endcap Muon Track Finder(EMTF)
  - 12 sectors of EMTF sends up to 4 muon candidates to Global muon triggers
  - GMT combines muon candidates from the three subsystems



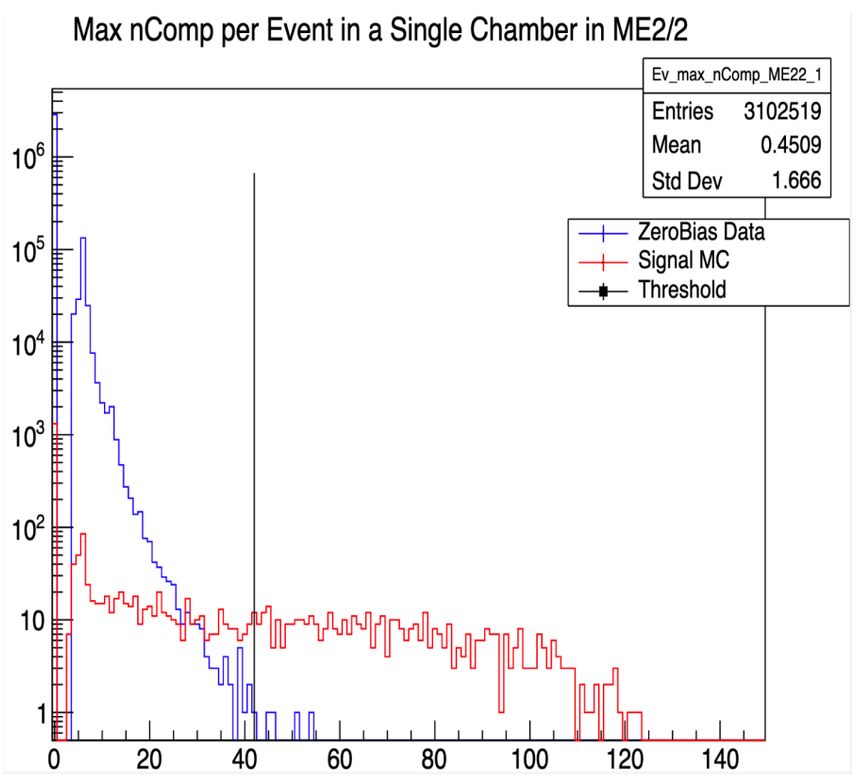
LLP Shower in Cathode Strip Chambers (CSC)

- Charge particles passing CSC produce cathode/anode signals
  - count hits in cathode/anode in each chamber
- Compare hit distributions for signal MC with zero-bias data from 2018
  - Define thresholds for cathode/anode per chamber
  - Trigger on the event if at least 1 chamber pass the threshold
  - Benchmark signal model:
    H->ss->4b with $c\tau$ ranging from 0.1m to 100m

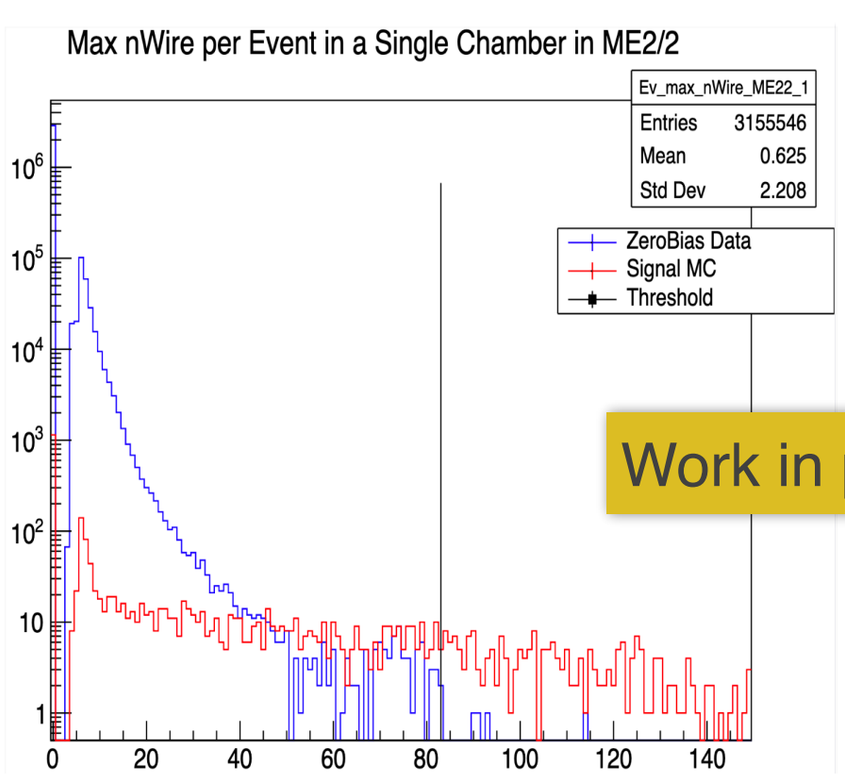




Cathode



Anode



Work in progress

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Optimizing threshold at L1

- Optimized the thresholds per chamber based on $\mathrm{eff}/\sqrt{\mathrm{rate}}$
  - Lower threshold for outer chambers
  - Typically need larger thresholds for anode wires (i.e. lower efficiency)

- Define 3 sets of thresholds (Loose/Nominal/Tight)
  - Give the rates (0.2 - 0.8 kHz)
    Takes up a small bandwidth of total 100 kHz in L1
  - Average signal efficiency 30-38% (Cathode)
  - <1% signal acceptance with MET trigger for the same signal

Bit	Meaning
0bXX00	No Shower
0bXX01	Loose Shower
0bXX10	Nominal Shower
0bXX11	Tight Shower

- Pack the presence of shower (of each type) into 2 bits per chamber
  - Propagate to global trigger decision

Nominal thresholds in each chamber

	ME1/1	ME1/2	ME1/3	ME2/1	ME2/2	ME3/1	ME3/2	ME4/1	ME4/2	Rate (kHz)	Eff.
Comp	98	56	30	49	42	49	35	42	31	0.53	34.5%
Wire	104	99	32	133	83	130	74	127	88	0.63	24.2%

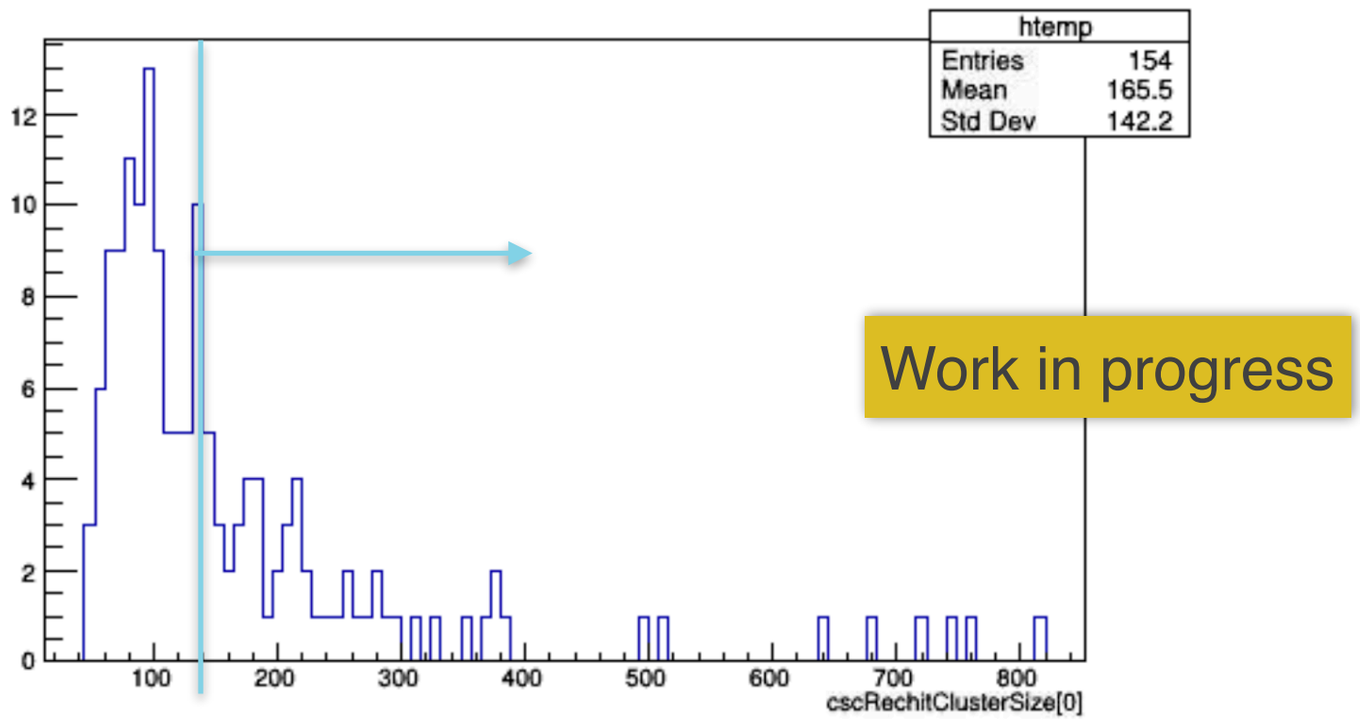
Higher in z

Work in progress

HLT Path

- Assuming L1 provides information of the presence of shower, design an HLT path selections that gives O(1)Hz rates
- Run offline reconstruction sequence
  - Cluster rechits from all chambers into clusters
  - Reduce rate with cluster properties (e.g. cluster size)
- Rate estimation:
  - Use events from list that pass the L1 trigger => normalize that rate to 530 Hz

Number of rechits in a cluster



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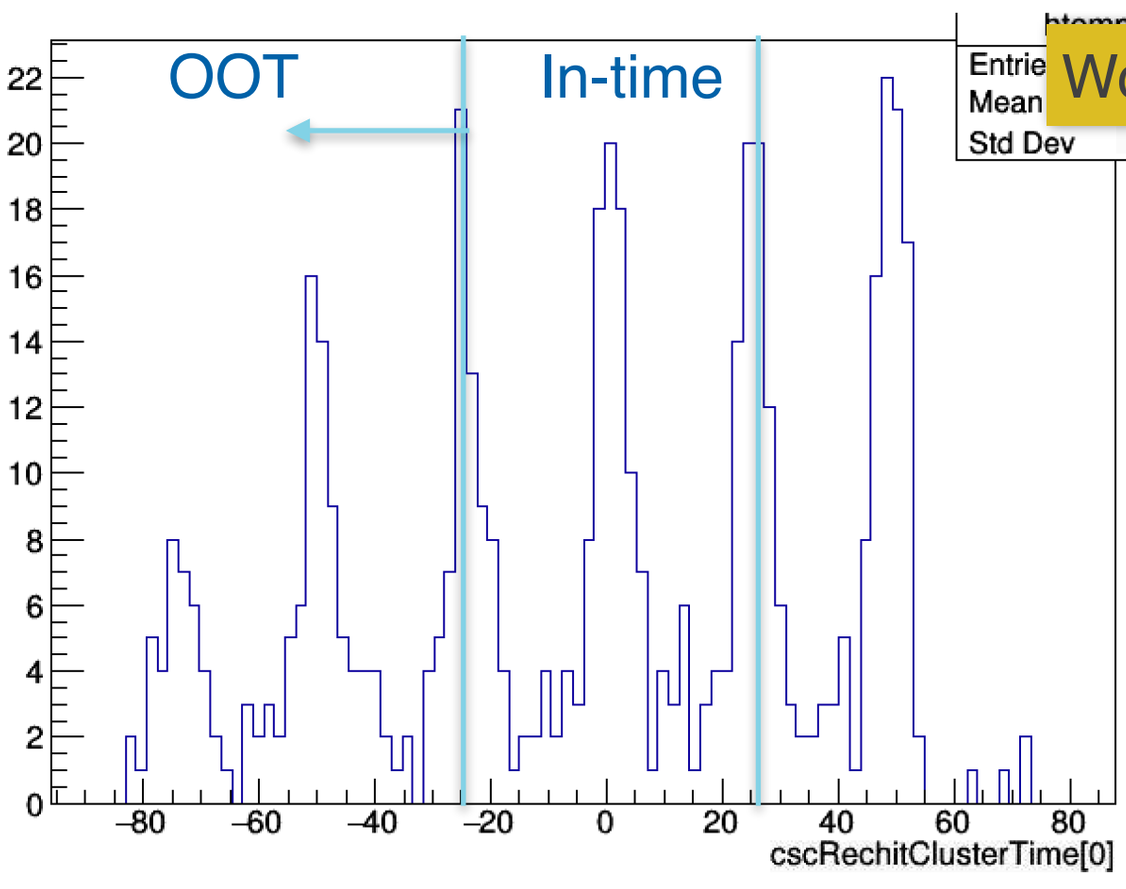
HLT Path

- Nominal selections:
  - At least one cluster with N_rechit >X
  - ME11/12 veto (Reduce noise from punch through jets in the first stations)
  - In-time (with +/- 1 BX)
  - letal <1.9
- Rate can comfortably fit within 1 Hz
  - Can further reduce rate with jet veto/MET requirement

N_rechit	Trigger Rate	Signal efficiency	Signal efficiency ratio with MET>200
N_rechit >100	12.5 Hz	9.3%	x 29
N_rechit > 200	2.5 Hz	7.1%	x 22
N_rechit > 225	**1.5 Hz**	**6.6%**	**x 20.6**
N_rechit > 275	**0.8 Hz**	**5.7%**	**x 17.8**

Out-of-Time(OOT) Control trigger

- We expect signal to be in-time
  - One important (irreducible) background is the LLPs from SM produced in pile-up interactions: neutrons, Kaons
  - Monitoring background rate from out-of-time (OOT) region will be very useful for studying background properties
  - Propose a pre-scaled control HLT trigger inverting the in-time selection (~0.1-0.2 Hz)
    - Extra bandwidth available in L1 for control paths



Work in progress

Cluster time distribution
From zero-bias data

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Integrating into muon trigger system

- Presence of shower in each chamber
  => Endcap Muon Track Finder (EMTF) [decision per sector]
  => uGMT [Muon system trigger decision]
  => Global Trigger

- Proposed logic at each stage:
  - Each chamber:
    2 bit for in-time, 2 bit for OOT, each encoding 4 values (no, loose, nominal, tight showers)
  - EMTF: At least one chambers in the sector has a nominal shower (1 bit in-time, 1 bit OOT)
  - uGMT: Encode number of showers in all sectors into 2 bits (0,1,2,3+) send 4 bits to global trigger (2 bits in-time, 2 bits OOT)

- Completely independent of muon reconstruction path
- Implementation underway
  - Both at the firmware and software levels

Summary

- CMS Muon system can act as an sampling calorimeter to capture LLP decay into hadronic showers
- Dedicated trigger for showers in CSC could extend CMS's reach for LLP with lifetime > 1m
  - Can improve acceptance by 20-30x
  - On-track to be brought online in CMS Run 3
- Make use of unused bandwidth in existing trigger system
  - Parallel trigger paths for muon showers/real muons
- The new path targets generic shower signature in CSC
  - Minimal signal dependence to benefit the most LLP models
  - e.g. Heavy neutral leptons